Spencer, M., Pyne, D., Santisteban, J., Mujika, I. (2011). Fitness determinants of repeated-sprint ability in highly trained youth football players. *International Journal of Sports Physiology and Performance*, 6(4), 497-508.

International Journal of Sports Physiology and Performance, 2011, 6, 497-508

Fitness Determinants of Repeated-Sprint Ability in Highly Trained Youth Football Players

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Variations in rates of growth and development in young football players can influence relationships among various fitness qualities. ***Purpose:*** To investigate the relationships between repeated-sprint ability and other fundamental fitness qualities of acceleration, agility, explosive leg power, and aerobic conditioning through the age groups of U11 to U18 in highly trained junior football players. ***Methods:*** Male players (n = 119) across the age groups completed a fitness assessment battery over two testing sessions. The first session consisted of countermovement jumps without and with arm swing, 15-m sprint run, 15-m agility run, and the 20-m Shuttle Run (U11 to U15) or the Yo-Yo Intermittent Recovery Test, Level 1 (U16 to U18). The players were tested for repeated-sprint ability in the second testing session using a protocol of 6 × 30-m sprints on 30 s with an active recovery. ***Results:*** The correlations of repeated-sprint ability with the assorted fitness tests varied considerably between the age groups, especially for agility (r = .02 to .92) and explosive leg power (r = .04 to .84). Correlations of repeated sprint ability with acceleration (r = .48 to .93) and aerobic conditioning (r = .28 to .68) were less variable with age. ***Conclusion:*** Repeated-sprint ability associates differently with other fundamental fitness tests throughout the teenage years in highly trained football players, although stabilization of these relationships occurs by the age of 18 y. Coaches in junior football should prescribe physical training accounting for variations in short-term disruptions or impairment of physical performance during this developmental period.

Keywords: maturation, acceleration, explosive power, agility, aerobic fitness

The sports science literature on repeated-sprint ability specific to field-based team sports has increased considerably in recent years.[1–3] This attention has come from both researchers and trainers/practitioners interested in quantifying this aspect of fitness for team sports. We recently documented the development of repeated-

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sprint ability in highly trained male youth association football (soccer) players and showed that this fitness quality improves substantially with age from under 11 y (U11) to U15, although a plateau occurs from the U15 to U18 age groups.[4] A recent study has examined the association between repeated-sprint ability and acceleration and maximum running speed in highly trained male junior football players[5]; however, the relationships between repeated-sprint ability and other fundamental fitness qualities of agility, explosive leg power, and aerobic conditioning in these age groups have not been determined. To our knowledge, there are no published data examining these relationships with a cohort of highly trained youth football players.

While there is a scarcity of information relating repeated-sprint ability and other fitness attributes in young association football players,[5] several studies have investigated maturation and physical performance throughout various ages of elite/highly trained[6,8] or nonelite[6,9,10] groups. In general, these studies report that the estimated peak height velocity occurs at an age of approximately 13.5 to 14.5 y (in males) and rapid increases in physical performance (ie, speed, agility, explosive power, aerobic endurance, anaerobic capacity) take place during this period. Further improvements after the peak height velocity are also evident in some fitness qualities. For example, a 5-y longitudinal study of youth football players of various competitive standards reported that additional improvements in explosive power (vertical jump and standing long jump), speed (30-m sprint), and anaerobic capacity (300-m shuttle run) were apparent after peak height velocity, when compared with other fitness qualities.[6] Furthermore, 30-m sprint performance showed an inverse relationship with height growth 1 y before peak height velocity, although performance rapidly increased thereafter and sprint velocity peaked at peak height velocity.[6] The authors stated this response of "adolescent awkwardness," a disturbance of motor coordination, was quite individual and in agreement with previous research.[11]

Variations in the performance of fundamental fitness qualities are evident when players are grouped by chronological age. Comparison of different groups should account for the biological maturity or muscle mass differences among players.[7] However, according to the rules of most football federations worldwide, players must compete within distinct age groups. Coaches and trainers require a more detailed understanding of the relationships and variations with age, in order to obtain a greater appreciation of the individual patterns of growth and potential short-term disruptions of performance during the adolescent years. The main purpose of this study was to investigate the relationship between repeated sprint ability and tests of 15-m sprint, 15-m agility, countermovement jump, and aerobic power. A second aim was to determine how these relationships differed through the age groups in highly trained boys and adolescent association football players (age groups U11 to U18).

Methods

Subjects

A total of 119 highly trained youth male football players participated in this investigation (U11, $n = 21$; U12, $n = 14$; U13, $n = 13$; U14, $n = 16$; U15, $n = 17$; U16, $n = 14$; U17, $n = 16$; U18, $n = 8$). All subjects were members of the development program of the same professional football club, and involved in regular U11 to U18 football competition at the time of the study. The U11 and U12 groups trained three

1.5-h sessions per week and played a 60-min match on the weekend. The U13 and U14 groups had four weekly training sessions of the same duration and a 70-min match. The U15 and U16 groups trained four to five times per week and played an 80-min match, whereas the U17 and U18 groups also trained four to five times per week but played a 90-min match. Written consent was obtained from the subjects' parents/guardians after being informed of the purpose and potential risks of participating in the study. All experimental procedures were approved by the Ethics Committee of the Universidad del País Vasco—Euskal Herriko Unibertsitatea.

Experimental Design

The experimental procedures took place during the second third of the competitive season (January–March). All subjects participated in two testing sessions separated by 3-4 wk. In the first session, anthropometric measures were collected and players completed a fitness assessment battery including countermovement jumps (CMJ) without and with arm swing (ACMJ), 15-m sprint run (15-m Sprint), 15-m agility run (15-m Agility), the 20-m Shuttle Run (20-m SR; U11 to U15) and the Yo-Yo Intermittent Recovery Test, Level 1 (Yo-Yo; U16 to U18). The 20-m SR test was used during the players' early phase of growth and development (≤ U15), and the Yo-Yo was used once repeated-sprint ability had stabilized, based on the findings from our previous study.[4] In the second testing session, the players were tested for repeated-sprint ability.

All players from each team followed the same training program established by their respective team coaches, and were familiar with all testing procedures. Testing sessions were carried out at least 3 d after the last competition match, at the same time of the day (17:00 to 20:30), and under the same experimental conditions. Team training intensity and volume was reduced the day before testing, and players were instructed to follow their usual diet on the days before to testing. No food was allowed in the 2–3 h before testing. The testing sessions were conducted on a different day for each age group and only one player was tested at a time for all sprint, agility, and jump assessments. Alternatively, all players from the respective age group were tested simultaneously for the assessment of either 20-m SR or Yo-Yo. The players were instructed, and verbally encouraged, to give a maximal effort during each of the fitness tests. All jumping tests took place on a cement surface with the players wearing running shoes, whereas all running tests were performed on a synthetic pitch and players wore studded football boots.

The first testing session started with the assessment of players' body mass (JWI-586, Jadever Scale Co., Ltd., Wu-Ku Hsiang, Taiwan) and height (T201, ASIMED S.A., Sant Adrià del Besós, Spain). Fitness testing started after a 10-min standardized warm-up consisting of low-intensity forward, sideways, and backward running; acceleration runs; skipping and hopping exercises; and jumps of increasing intensity.

Countermovement Jumps

The countermovement jump (CMJ) and countermovement jump with arm swing (ACMJ) were performed on a contact platform (Ergo Tester, Globus Italia, Codognè, Italy). All jumps were initiated from a stationary standing position, followed by a preparatory countermovement consisting of a 90° knee flexion. The players were instructed to keep their hands on their waists during the preparatory and the jump phases for the CMJ testing, whereas during ACMJ they were allowed to swing their arms for impulse during the preparatory and jump phases. Flight time was registered by a digital timer connected to the contact platform for calculation of the height of the jump.[12] Each player performed two maximal CMJs and two maximal ACMJs interspersed with 3 min of rest, and the best jump score, in centimeters, was retained.

Fifteen-Meter Sprint Run (15-m Sprint)

Ten minutes after completion of the jump tests, players performed the 15-m Sprint test.[13] In this test, elapsed time and velocity in a 15-m straight-line sprint was measured by photocell timing gates placed 1.0 m above the ground (Timer S4, Alge-Timing, Lustenau, Austria). Each sprint was initiated from a "ready" standing position, 3 m behind the photocell gate, which started a digital timer. The aim was not to obtain a stationary sprint time, but a 15-m time with a 3-m run-up, as accelerations in football usually commence from a position of motion. When players crossed the second set of photocell gates placed at a distance of 15 m, average velocity, in meters per second, was displayed and recorded. Each player performed two maximal 15-m sprints interspersed with 3 min of passive recovery, and the fastest velocity ($m \cdot s^{-1}$) achieved was retained.

Fifteen-Meter Agility Run (15-m Sprint)

Five to ten minutes after the 15-m Sprint, players performed the 15-m Agility test. In this test, players' velocity in a 15-m agility run was measured with the photocell gate system. As in the 15-m Sprint, players started running 3 m behind the initial set of gates, which started the timer; they continued running 3 m to a slalom section marked by three poles 1.6 m high and placed 1.5 m apart; cleared a 0.5-m hurdle placed 2 m beyond the third stick; and finally ran 7 m to the second (finishing) set of photocell gates (Figure 1). Each player performed two maximal 15-m Agility trials interspersed with 3 min of passive recovery and the fastest velocity ($m \cdot s^{-1}$) achieved was retained.

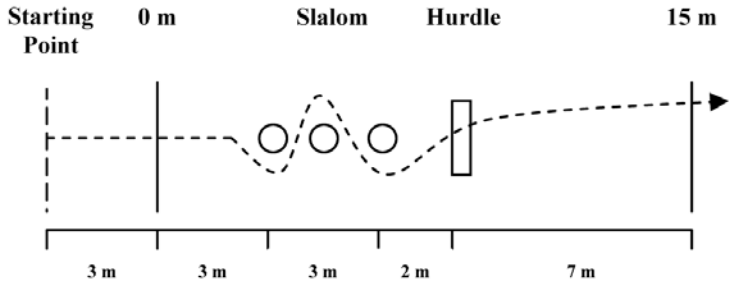

Figure 1 — Schematic representation of the 15-m agility run.

20-Meter Shuttle Run (20-m SR)

Ten minutes after the 15-m Agility test, players aged U11 to U15 performed the 20-m SR test, a valid and reliable test for the prediction of maximal oxygen consumption.[14] The 20-m SR consisted of continuous 20-m shuttle runs performed at progressively increasing velocity. Players paced themselves against audio cues broadcast from a portable CD player. The test finished when a participant failed twice to reach the 20 m line in time. The number of the last completed level and shuttle was then converted to a decimal, in addition to the total distance covered.

Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo)

Players in the U16, U17, and U18 groups performed the Yo-Yo.[15] The Yo-Yo consisted of 20-m shuttle runs performed at progressively increasing velocity and interspersed with 10 s of active recovery after every out and back (ie, 40 m) shuttle. Players paced themselves against audio cues broadcast from a portable CD player. The test finished when a participant failed twice to reach the finish line in time with the beeps on two consecutive shuttles. The total distance covered during the test, including the last incomplete shuttle, was the final test value.

Repeated-Sprint Ability

Repeated-sprint ability testing was undertaken 5 min after a standardized and supervised 16-min warm-up that included low-intensity forward, sideways, and backward running; skipping exercises; four acceleration runs over 40 m; and four 10- to 30-m sprints at maximal speed. The repeated sprints were performed on an indoor synthetic football pitch. Testing consisted of 6 repetitions of a 30-m maximal sprint[16] departing on a 30 s cycle. Time in each 30-m straight-line sprint was measured by means of photocell gates placed 1.0 m above ground level (Timer S4, Alge-Timing, Lustenau, Austria). Each sprint was initiated from a "ready" standing position, 0.3 m behind the photocell gate, which started a digital timer. When players crossed the second set of photocell gates, placed at a distance of 30 m from the start, the sprint velocity was displayed and recorded, then subsequently converted to sprint time. On completion of each 30-m sprint, subjects decelerated to a cone placed 10 m beyond the 30-m mark, turned around, and completed a moderate intensity jog (2.0–2.2 $m \cdot s^{-1}$) back to the start line within 18–20 s to ensure 4–6 s of passive recovery before commencement of the next sprint. Subjects received verbal feedback while jogging back to the start line to ensure they were ready for the subsequent sprint within the allocated time. The repeat sprint total time was the sum of all six sprint times, expressed in seconds.[16] The reliability of this test is high (typical error = 0.7%, 95% confidence limits, 0.5–1.2%).[16]

Statistical Analysis

Descriptive statistics are presented as mean ± standard deviation (SD). To make inferences about the true (unknown) population value of the estimate, the uncertainty was expressed as 90% confidence intervals (CI). Pearson's product-moment correlation analysis was used to compare the degree of association between the results from the repeat sprint total time with the other performance measures of

15-m Sprint, 15-m Agility, CMJ, ACMJ, 20-m SR, and Yo-Yo tests. The following criteria were adopted for interpreting the magnitude of correlation (r) between the measures: < .1, trivial; .1–.3, small; .3–.5, moderate; .5–.7, large; .7–.9, very large; and .9–1.0, almost perfect. Differences between correlations were compared using a Fisher's Z transformation: a default threshold of $r = .1$ was used as the smallest practically important difference.[17]

Results

The highly trained nature of the youth football players is indicated by the physical and performance characteristics of each age group (Table 1). In general, the correlations between the repeat sprint test were moderate to very large with sprinting, trivial to very large with agility, moderate to large with jumping, and small to moderate with the shuttle endurance tests.

A surrogate measure of peak height velocity is shown in Figure 2. Peak height velocity is typically computed as within-subject measure in a longitudinal study. Here in this cross-sectional study we plotted the difference in height between consecutive age groups (eg, 12–13 y, 13–14 y, and so on). The figure shows that the peak height velocity is most likely to occur in the 13–14 y of age period.

Large to very large correlations between 15-m Sprint and repeat sprint total time were evident for the majority of age groups, with the exception of the U14, U16, and U17 groups, where the correlations were moderate (r = .48 to.58; Figure 3a). The correlations between 15-m Agility and repeat sprint total time were highly variable, ranging from trivial for U16 and U17 to large–very large for U11, U13, and U18 groups (Figure 3b). The greatest difference in correlations for two successive age groups was for the U17 and U18 groups, with r = .02 (CI: –0.44 to 0.47) and r = .92 (0.73 to 0.98) respectively. Moderate-to-large correlations were apparent between CMJ and repeat sprint total time for all groups, with the exception of the U14 group, where the correlation was trivial (r = .04; –0.46 to 0.53; Figure 3c). Similarly, moderate-to-large correlations were reported between ACMJ and repeat sprint total time, again with the exception of a trivial association for the U14 group (r = .10; –0.41 to 0.57; Figure 3d). Small-to-moderate correlations between 20-m SR and repeat sprint total time were evident among the five age groups that completed the 20-m SR test, with the highest correlation being for the U11 group (r = .68; 0.38 to 0.86; Figure 3e). Small-to-moderate correlations between Yo-Yo and repeat sprint total time were also apparent for the three age groups that completed the Yo-Yo test (Figure 3f).

Discussion

This is the first study, to our knowledge, that has described the relationships between repeated-sprint ability and a complete test battery of the fundamental fitness tests of acceleration, agility, explosive power, and aerobic conditioning in highly trained male youth football players, and how these relationships differ (in a cross-sectional study) through the ages of 11–18 y. The present data show that repeated-sprint ability is, in general, highly correlated with other aspects of physical performance, but some variability in these relationships between age groups in the adolescent

Table 1 Physical and performance characteristics of the male youth football players through the age groups U11 to U18 (mean ± SD)

Age Group	Height (cm)	Mass (kg)	Repeat Sprints (s)	CMJ (cm)	ACMJ (cm)	15 m Sprint (m/s)	15 m Agility (m/s)	Shuttle Run (Decimal)	Shuttle Run (m)	YYIRT1 (m)
U11	145.8 ± 4.4	38.2 ± 4.2	33.1 ± 1.8	26.3 ± 2.8	30.6 ± 3.2	5.9 ± 0.2	4.0 ± 0.2	9.3 ± 1.1	1,522 ± 236	—
U12	150.0 ± 5.6	41.4 ± 3.2	32.2 ± 1.3	28.5 ± 4.2	32.5 ± 4.3	6.0 ± 0.2	4.3 ± 0.1	10.1 ± 1.0	1,704 ± 225	—
U13	157.3 ± 7.9	46.4 ± 6.1	30.9 ± 1.7	31.1 ± 4.3	36.6 ± 5.2	6.1 ± 0.2	4.4 ± 0.2	10.7 ± 1.0	1,848 ± 230	—
U14	166.9 ± 6.4	55.2 ± 9.3	28.7 ± 0.6	36.7 ± 4.7	40.9 ± 4.2	6.6 ± 0.2	4.7 ± 0.2	12.1 ± 1.3	2,159 ± 302	—
U15	172.9 ± 7.0	60.3 ± 4.9	27.2 ± 0.8	40.2 ± 4.3	46.0 ± 5.2	6.9 ± 0.2	4.7 ± 0.2	12.5 ± 0.9	2,259 ± 214	—
U16	175.2 ± 7.0	66.6 ± 7.4	26.8 ± 0.7	42.3 ± 4.6	47.6 ± 4.7	6.9 ± 0.2	4.7 ± 0.2	—	—	2,374 ± 375
U17	179.4 ± 7.2	70.8 ± 8.4	26.7 ± 0.6	40.7 ± 3.4	46.8 ± 3.3	7.1 ± 0.2	4.8 ± 0.2	—	—	2,340 ± 401
U18	176.7 ± 8.4	70.3 ± 7.8	26.2 ± 0.8	44.5 ± 6.1	50.9 ± 6.5	7.2 ± 0.3	4.9 ± 0.3	—	—	2,715 ± 547

Note. CMJ = countermovement jump; ACMJ = countermovement jump with arms; YYIRT1 = YoYo Intermittent Recovery Test Level 1.

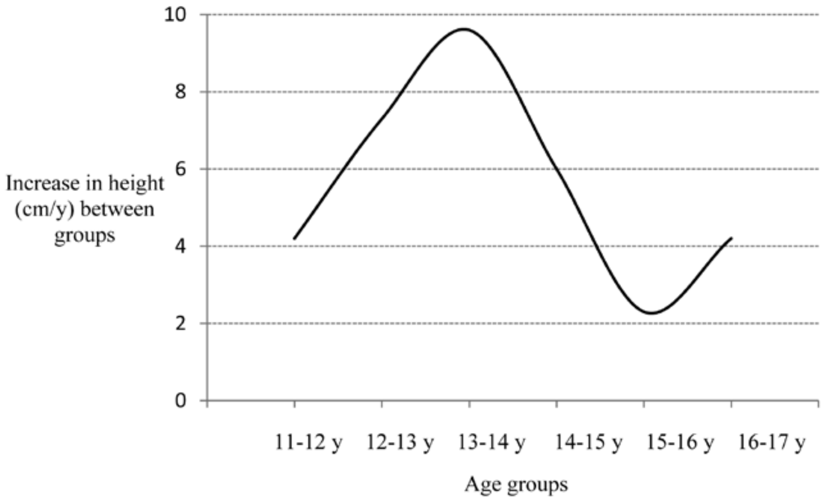

Figure 2 — Difference in mean height (cm·y^{-1}) between consecutive age groups in the cross-sectional study. The data indicate that the 13- to 14-year-old group is likely to have the highest peak height velocity.

years may be evidence of minor disruption in motor coordination abilities. The major finding of this study was that the correlations of repeated-sprint ability with agility and leg power varied considerably between the individual age groups. In contrast, the correlations of repeated-sprint ability with acceleration and aerobic conditioning were more consistent across the respective ages.

The moderate-to-very large correlations of repeat sprint total time with 15-m Sprint, in our study, are consistent with the findings of Mendez-Villanueva et al,[5] who investigated the correlations of a very intense repeated-sprint test (10 × 30-m sprints) with acceleration (10-m sprint) and maximum running speed (flying 20-m sprint) in three groups of junior (U14, U16, and U18) football players. Furthermore, the present findings are in support of those of Pyne et al,[3] who reported a moderate correlation (r = .66) between a repeated-sprint test consisting of 6 × 30-m sprints and 20-m sprint time in highly trained junior male Australian Rules football players. Other studies have reported that repeated-sprint ability is closely related to anaerobic factors, such as muscle phosphocreatine breakdown[18,19] and muscle buffer capacity.[20] An interesting observation in the present data was the uncoupling or variable correlations of repeat sprint ability with short sprints through the U14 to U17 age groups. The lack of a substantial association between these qualities may relate to variability in sprint performance during maturation compared with other fitness qualities.[6] For example, Philippaerts et al[6] reported an inverse relationship between 30-m sprint time and height growth in the 12-mo period before peak height velocity, although a positive relationship (improving performance) was evident at peak height velocity in their study of male youth football players.

The substantial variability in the correlations between agility and repeated-sprint ability throughout the range of age groups was a notable outcome of this study.

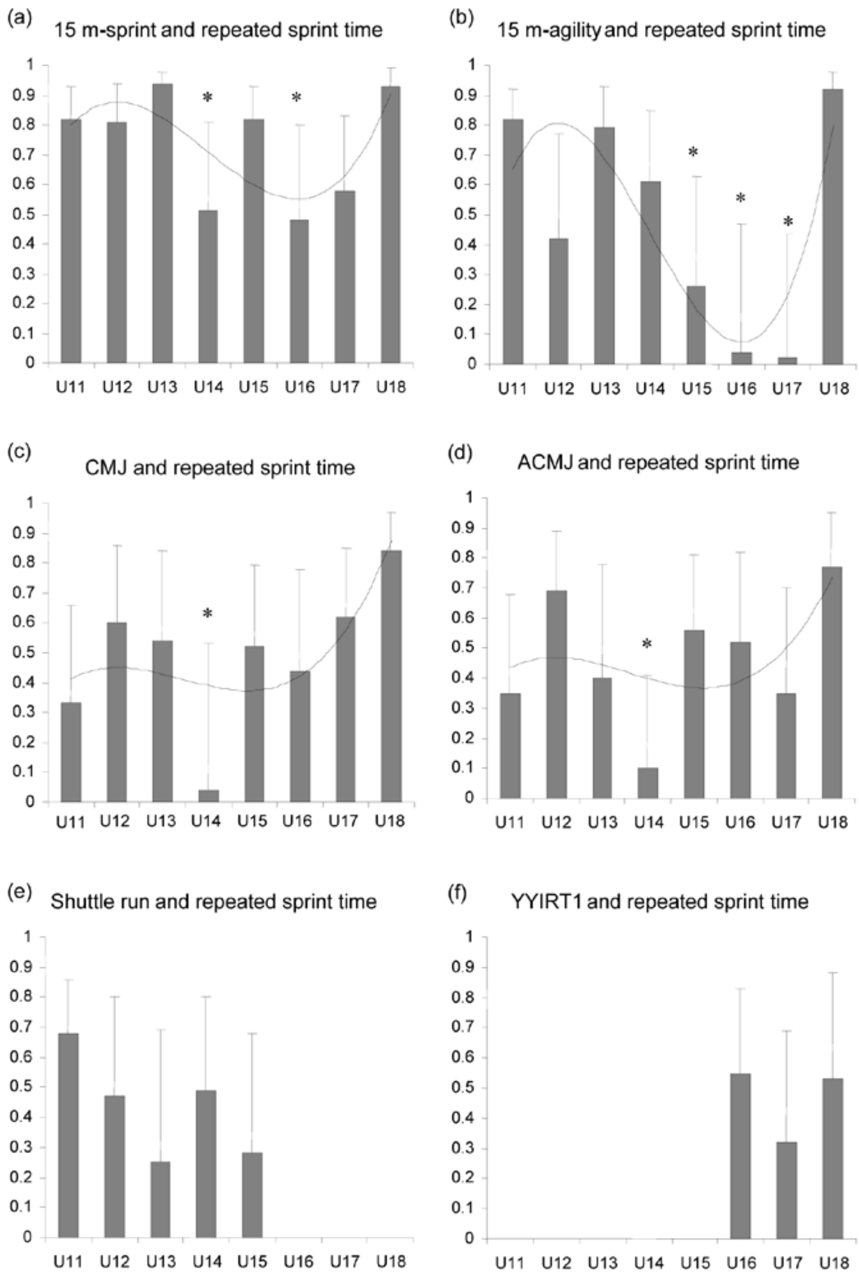

Figure 3 — Correlations between sprint, agility, explosive leg power, and aerobic fitness with repeated sprint times through the age groups of U11–U18 years in male youth football players (± 90% confidence limits). *Indicates substantially smaller correlation than highest correlation in this comparison. The fitted tread line is a third-order polynomial.

For example, we observed a trivial correlation between agility and repeated-sprint ability for the U16 and U17 groups but a very large correlation for the U18 group. It is acknowledged that this large difference between group correlations may partly be explained by factors other than the influence of maturity and training. The repeated sprint test was designed to involve maximal sprinting in a straight line, minimizing the coordination or skill component. Conversely, the agility test was quite technical and required good coordination skills. The lack of association between these qualities in the 14- to 16-year-old players is possibly related to a disruption in motor coordination of individual players during this developmental period.[11] This period of adolescent awkwardness is thought to be related to disproportional growth in leg length relative to trunk length.[7] It is possible that greater variability in complex motor coordination tasks (agility and jumping), compared with the simpler tasks (straight-line running) was associated with temporary disruption of motor coordination. Individual variations in motor coordination and other performance tasks that occur during the mid-teenage years generally dissipate by the age of 18 y.[11] It is therefore important that coaches and players are educated on the possibility of short-term impairments in physical performance in the mid-adolescent years.

Moderate-to-large correlations were observed between jumping and repeated sprint ability in the youth football players. However, there were some variations in these relationships for different age groups, suggesting the differential influence of upper-body strength or muscle coordination when the arm swing is included in the test.[21] The U14 age group was clearly different from all other groups, with trivial correlations for both tests of explosive leg power. The estimated peak height velocity occurs in this particular age group[6,7] and explosive power shows peak development at this approximate time; these peaks may partly explain the disparity when compared with repeated-sprint ability,[6] when individual developmental variations within the age group are considered. However, there is currently limited data regarding the peak development of repeated-sprint ability, in relation to peak height velocity. We have recently reported that the greatest performance differences in repeated-sprint ability, when assessing highly trained youth football players (U11 to U18), occurred from the U13 to U14 age groups, in which we also observed the most marked differences in body mass and height.[4] In addition to the anthropometric changes occurring during this growth phase, significant physiological changes also occur during these years, such as motor unit recruitment, muscle fiber diameter, and the rate of phosphocreatine replenishment and substrate availability.[22] More research is required to further investigate the underlying physiological and musculoskeletal changes explaining the variable relationships between explosive power and repeated-sprint ability through the period of maximal growth spurt in diverse cohorts of developing team-sport athletes. This information would aid in providing specific advice to coaches and conditioners in training their junior players.

The small-to-moderate correlations between tests of aerobic conditioning (20-m SR or Yo-Yo) and repeat sprint total time, for all age groups, are consistent with data using a similar test of repeated-sprint ability in highly trained young Australian Rules football players.[3] Therefore, this suggests that the fitness qualities of aerobic conditioning and repeated-sprint ability are quite different in this population of young footballers. However, it must be noted that other studies have reported larger correlations between tests of aerobic conditioning and repeated-sprint ability,[23] and that this relationship, in addition to the energy system contribution of the repeated-sprint test, depends largely on the individual variables of the protocol, such as sprint number, sprint duration, recovery duration, and recovery intensity.[1,24] We suggest that the assessment of repeated-sprint ability, where possible, be specific to the team sport and sample group studied. With regards to association football, this process of documenting the repeated-sprint activity during games[25] and specific assessment of repeated-sprint ability[26] has to date only been undertaken in elite women's football.

Practical Applications

Coaches and athletes in the adolescent years should be educated on the possibility of short-term disruptions or impairment of physical performance during the mid-adolescent years. Coaches and physical trainers should be mindful of individual patterns of growth during this period and variable changes in test performance. In particular, players are likely to experience more variability in complex motor coordination tasks, such as agility and explosive power tests and training drills, compared with the simpler tasks of straight-line running tests.

Conclusions

Relationships between repeated-sprint ability and other fundamental fitness tests (acceleration, agility, explosive power, and aerobic conditioning), vary substantially through the age groups of U11 to U18 in highly trained youth football players. This uncoupling was especially evident between repeated-sprint ability and tests of agility and explosive power. The correlations of repeated-sprint ability with acceleration and aerobic conditioning were less variable with age. Furthermore, the U18 age group displayed the highest correlations for repeated-sprint ability when compared with the acceleration, agility, and explosive leg power tests, suggesting that stabilization of overall physical performance is evident in this age group.

Acknowledgments

The authors gratefully acknowledge the technical assistance of Athletic Club Bilbao's coaching and medical staff during the testing sessions, as well as the participating players for their enthusiasm and cooperation.

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